

Research Brief for DOE/IHEA Process Heating Materials Forum

Research Title: Monolithic and Surface Modified Ceramics

The proposed research has two tasks. Task 1 will ultimately enable the use of advanced ceramics for use in process heating components through their systematic thermomechanical characterization, probabilistic design and life prediction, and remaining life assessment. Task 2 will develop ceramic coatings with enhanced environmental resistance (high temperatures, corrosion, oxidation) through improvements in the composition and processing of the coating.

Industry Need:

The utilization of advanced ceramic components and components having enhanced environmental resistance in industrial heat generation, heat transfer, heat containment, waste heat recovery, and emission control applications will increase lifetime over that of existing components and lessen service downtime and operation costs. The desired common denominators among these applications are components that have maximum thermomechanical robustness and corrosion resistance; this research addresses the improvement of both by considering components (e.g., heat exchangers, nozzles, tubes, fans, baffles, etc.) that are appropriately designed and fabricated with alternative advanced ceramics (e.g., SiC, Si₃N₄, SiAlON, cordierite, etc.) or that are protected by advanced coatings.

Existing Research:

Task 1.

The use of advanced ceramics in components for industrial heating processes can be enabled (and the lifetime of those existing ceramic components can even be increased or operated at more severe thermomechanical service conditions) if appropriate probabilistic design practices are employed. A general and established probabilistic design method is illustrated in Fig. 1 for structural ceramic components. Existing expertise and capabilities in ORNL's Structural Ceramics Group (SCG) permit the execution and generation of the left-hand side of the algorithm shown in Fig. 1. The investigators have a substantial amount of experience in the mechanical testing of both structural and non-structural ceramics and in the interpretation of how microstructure and flaw populations can limit and be modified to enhance performance of both large and small components (e.g., ceramic valves, refractory nozzles used in steel production, thermally-shocked ceramic substrates, etc.). The SCG staff in the structural ceramics group utilizes finite element analysis to model the thermomechanical stress state of a component, and combines (right-hand-side of Fig. 1) their results with censored Weibull strength and fatigue data of the candidate ceramic to predict survivability and lifetime. The execution of such an algorithm has been instrumental for the successful design and use of ceramic components in many applications where the inherent higher temperature capability and wear-resistance of ceramics improved efficiency.

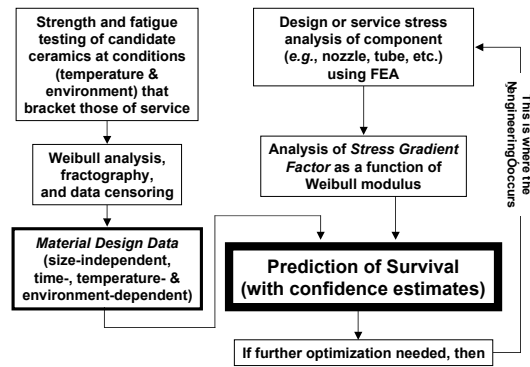


Figure 1. Probabilistic design and life prediction algorithm used for structural design of monolithic ceramic components that will be used in this proposed project.

Task 2.

The development of novel coatings utilizing low-cost processing methods or surface modification techniques such as dip coating and conversion coatings are being pursued. There are numerous slurry-based approaches including dip coating, screen-printing, spin coating, spray coating, and vacuum coating. All processes have indicative advantages and challenges. Currently, the use of slurry based coatings such as dip coatings are being investigated utilizing a glazing approach (a ceramic powder suspended in an aqueous medium). The substrates are coated by the slurry and are densified by either conventional sintering or utilizing the “High Density Infrared Sintering” process (HDI). In either approach, the coating can be composed of the desired end composition or reactants that combine to form the end coating composition. Ultimately, there is a need for the development of materials with improved stability in these harsh environments that can be applied through a low-cost processing route such as slurry coating.

Proposed Activity:

Task 1 will combine thermomechanical characterization of ceramics that are candidates for components used industrial heat applications and probabilistic service life prediction and design of those components using statistical models that were specifically developed for structural ceramic component design. Components (whose replacement with components made of advanced ceramics would improve performance and lessen production downtime) would be of focus.

Task 2 will develop ceramic coatings with enhanced environmental resistance (high temperatures, corrosion, oxidation) through improvements in the composition and processing of the coating. Processing innovations will focus on reactive aqueous coating development. This will include the use of HDI to densify in-situ refractory-based composition coatings. The HDI process enables materials that have high sintering temperatures to be densified without degradation of the substrate due to the limit of thermal penetration. Another reactive coating process that will be evaluated is the use of polymeric, organo-metallic or colloidal solutions of base materials that will react in-situ to form an enhanced material or microstructure. Candidate materials will be exposed in facilities at ORNL and will be characterized to identify the most promising materials for specific applications.

Lead Scientists:Monolithic Ceramics

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